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Mapping Fire and Fuels Characteristics Using Remote Sensing and Biophysical Modeling for Operational Fire Management Project ID: AFRR-0000-0175

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A FINAL REPORT

submitted to
NASA Remote Sensing Applications Research in
Agriculture, Forestry, and Range Resources Management
Research Announcement NRA-98-OES-09

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Period of Performance
June 1999 to October 2003

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Abstract

This is a final report for the project "Fire and Fuels Characteristics Using Remote Sensing and Biophysical Modeling for Operational Fire Management" (Project ID: AFRR-0000-0175). The purpose of this study was to develop methods and protocols for mapping fuels and fire hazard across multiple-scale landscapes using a combination of remote sensing and spatially explicit biophysical modeling. Digital fuels maps will allow the simulation of fire spread and intensity in a real-time and planning application. This study is composed of 12 tasks organized into three groups. The first set of tasks coordinates fuels mapping research by organizing an international symposium and establishing a web site. The second set conducts active research on fuels characterization linkages, comprehensive remote sensing fuels map classification, linking remote sensing to biophysical modeling, and assessment of EOS products ETM+, ASTER, MODIS, and Lidar. The third set integrates all this information software that comprehensively describe methods of mapping fuels at different scales, accuracies, and costs. This study concerns NRA-98-OES-09 Topical Priorities 4.1.2 (Forest and Range Vegetation Inventory and Characterization), 4.2 (Risk and Damage Assessment), and 4.3.1 (Resource Management). This final report will detail the accomplishments of each of these tasks and list the publications and products that were generated from this project.

Project Description

Background -- Comprehensive digital fuels mapping on federal and state lands is critical to modern fire management activities and several recent developments serve to emphasize the critical role fuels maps play in fire management. First, fire is now recognized as an essential natural process in many ecosystems and land managers are increasingly expected to use landscape-level fuels treatments to improve ecosystem health and to reduce likelihood of catastrophic fires. And second, an expanding urban interface and a highly litigious society have narrowed the margin for error in fire management decisions. Third, the last three years (2000-2003) have been the most severe in acres burned and number of fires since the great 1910 fire. As a result, fire managers are now required to use complex, data-intensive fire and smoke behavior models to support environmental assessments and burn plans. Moreover, fire managers must provide more accurate fire-behavior predictions for real-time support of suppression tactics and logistics decisions because of heightened concern for firefighter safety especially following the Storm King fire fighter fatalities. Electronic maps of surface and crown fuels allow the real-time simulation of fire spread and intensity and they also provide construction of fire hazard and risk maps for prioritizing and planning future fuels treatments. The mapping of fuels requires intensive identification of many vegetation characteristics, including plant composition, structure, and biomass, and forest floor characteristics including necromass, fuel size distribution, and depth.

Development of spatially explicit fire behavior and fire effects prediction models, such as FARSITE (Fire Area Simulator, Finney 1998), has revolutionized fire management prediction and decision support systems. These computer models allow managers to simulate, in real-time or planning modes, the spatial and temporal characteristics of wildland fires on a computer to more accurately predict future wildland fire growth and direction so they can plan or fight it more efficiently. However, these models require detailed electronic maps of fuels and vegetation characteristics to generate accurate and consistent fire behavior predictions. Ironically, the FARSITE model, which is available for free to anyone, requires extensive spatial vegetation and fuels layers that are quite costly and difficult to build (Keane et al. 1998a). Fire managers across the country are rapidly trying to learn this tool and obtain the input data needed to run the model for their area. FARSITE requires eight data layers for a comprehensive treatment of spatial crown and surface fire growth -- elevation, aspect, slope, fuel model (Anderson 1982), canopy closure, stand height, crown base height, and crown bulk density. All eight data layers must be of high resolution and reasonably accurate to effectively predict fire growth.

The Problem -- Most fire and land managers do not have the fuels and vegetation GIS layers needed to run many spatial fuel management decision support systems such as the FARSITE model. Most of the existing vegetation and fuels maps and databases do not quantify the fuels or vegetation information to the extent, detail, or resolution needed by managers for fire behavior or effects prediction. Moreover, many attempts to create fuels layers from existing maps have failed because of inexperience with fuels and vegetation modeling and mapping in the context of fire behavior and fire effects. Those projects where suitable FARSITE layers were created, such as the Selway-Bitterroot Wilderness Complex (Keane et al. 1998a) and Yosemite National Park (Van Wagtendonk 1998) have shown great promise but they are currently expensive and in need of refinement.

There are three main reasons why fuels maps are difficult and costly to create. First, most remotely sensed products used for mapping, such as aerial photos and satellite images, are unable to discriminate between important fuel types because the fuel bed is often obscured from view by

the forest canopy. Second, the most important input to fire management hazard and risk assessments is fire behavior. Fire behavior is currently simulated using FARSITE (Finney, 1998) and BEHAVE (Andrews, 1986) which rely on just 13 generalized fuel models (Anderson, 1982) to characterize fuels. These fuel models rarely match actual fuel loadings (Anderson 1982). As a result, many people who do not have experience in fire behavior or fuel model mapping are unable to estimate fuel model accurately and consistently (Burgan and Rothermel 1984). Third, all data layers for fire behavior prediction must be developed and mapped simultaneously and consistently so they are spatially congruent. This means stand crown height should not be taller than stand height, for example. Obviously, the creation of these data layers requires a great deal of experience in ground-truthing, image processing, remote sensing, vegetation mapping, fuels modeling, and fire management.

One frustrating aspect of fuel mapping is there are three different fuel classifications used to describe the fuelbed of a stand depending on the particular application. Fire behavior computer programs, such as FARSITE and BEHAVE, use fire behavior fuel models such as the 13 described by Anderson (1982). Fire danger computer models use the 20 NFDRS fuel models (Cohen and Deeming 1985) to consistently predict fire potential for the US. Fire effects prediction systems, such as FOFEM (Reinhardt et al. 1997) and CONSUME (Ottmar et al. 1997), require actual fuel loadings by fuel type and size class. Moreover, these three fuel classifications are comprised of different fuel categories. Therefore, fire behavior fuel models cannot be used for predicting fire effects such as in FOFEM, and vice versa; and therefore two different maps must be made.

In summary, land management agencies need methods, tools, and standards to create fuels layers that are useful for all phases of fire management for their area. And, since these layers cost a great deal of time and money, their development should produce maps and databases that are also useful to other fire and natural resource decision support systems.

Objectives

This fuels mapping project has one main objective.

> ***To develop methods and tools for creating spatial fuels layers for fire behavior and fire effects prediction systems and hazard and risk assessment***

The goal of the proposed research is to research and develop methods and protocols for creating high resolution fuels data layers for input to detailed fire management decision support systems including fire behavior, fire effects, site productivity, and smoke generation.

Phases and Task Report

This document is a final report summarizing the results of all the activities and research that was funded for this project. Several changes occurred during this study as reflected when one compares this final report with the original proposal. First, principle investigators were removed or added as they retired or were included for their contribution. Second, many tasks were added, modified, and removed as their importance to operational fuel mapping became evident. Third, the output products generated from this study are somewhat different from those specified in the proposal because this project was such a success and many more results were generated than expected. I've attempted to organize this final report in the same format as the proposal, but have added or modified the original tasks and have noted why these tasks were changed. Each task is numbered by phase then group (if applicable). Also, the principal investigators involved in each task are presented in parentheses after the task title. Last, there are still tasks in this project that haven't been completed so the ultimate output of products will be much greater than what is presented in this final report.

This NASA funded project was extremely successful for a wide variety of reasons. By linking the NASA study with other collaborative fuel mapping studies funded by the USDA Forest Service, USGS EROS Data Center, Joint Fire Sciences Program, and a wide range of University and private institutions, we were able to initiate and complete a large number of research projects that ordinarily couldn't have been done without the NASA monies. Without this collaboration, we would not have been able to obtain imagery, software, and databases owned or maintained by each of the institutions involved in this effort. Last, the collaboration of these scientists allowed us to work toward a common goal by linking related research into one objective. The synergy gained from the NASA collaboration allowed us to produce much more as a project than we could have ever done alone.

This fuel mapping project was successfully accomplished in three simultaneously occurring phases linked together by many tasks performed by 14 scientists. Information from all published or on-going fuels mapping efforts were summarized in the **Coordination** phase. The **Research** phase used the summarized information to develop new classifications, technologies, and methods to map fuels more accurately. The **Implementation** phase synthesizes results from first two phases into standardized protocols for use by fire and land managers for using the mapped fuels for fire hazard and risk prediction.

1.0 Coordination Phase

This first phase involves coordinating and synthesizing all current and historical fuels mapping activities so information on mapping methods and technology is readily accessible to fire management. This phase has been mostly funded by the USDA and USDI Joint Fire Sciences Program and several other funding sources.

Task 1.1- Summary of current research efforts (Keane). An extensive literature search was conducted to identify current and past fuels mapping attempts. This information was synthesized into a research document (Keane et al. 2001) published in the International Journal of Wildland Fire (see Product 1).

Task 1.2- Symposium on current research efforts (Keane, Neunschander, Sampson, Golberg). An international list of researchers and managers interested in fuels mapping and modeling was developed. These people, and all others interested, were invited to attend **an international**

symposium in Boise, ID in spring 1999 for the primary purpose of capturing the state-of-the-knowledge in the following four areas: 1) fuel, vegetation, and fire regime mapping, 2) fuel, fire behavior, and fire effects modeling, 3) fire hazard and risk modeling, and 4) fuel treatment technologies. This symposium was attended by over 200 fire managers and researchers and it generated two primary products. First, a collection of 17 invited papers were published in a special issue of the International Journal of Wildland Fire (IWJF) called "Integrating spatial technologies and ecological principles for a new age in fire management" (see Product 2). Next, a collection of over 100 submitted papers were published in a CD titled "Proceedings from the Joint Fire Science Conference and Workshop: Crossing the millennium: Integrating spatial technologies and ecological principles for a new age in fire management" (see Product 3). Both the special issue of IJWF and the CD were distributed to all conference attendees and over 200 people. This task was almost entirely funded by the Joint Fire Sciences Program.

Task 1.3- Web-Based Coordination (Keane, Golberg). All core products needed to map fuels, such as field data and base GIS layers (e.g., DEM, roads), must be easily assessable for fire management. This NASA project initiated the construction of a new web site called FRAMES, Fire Research And Management Exchange System (www.frames.gov) that attempts to compile, coordinate, and collect all the research, development, and operational spatial data products needed for fuels mapping among many other tasks. This web site has just been funded for over $300,000 by the National Fire Plan, Joint Fire Sciences Plan, and Rocky Mountain Research Station, and the fuels mapping portion of this web site is just starting to be developed. By 2006, the FRAMES web site will have all the links and databases needed to comprehensively map fuels at multiple scales. This will include:

1. An extensive georeferenced, plot-level, fuels loading database that can be used as training sites and ground truth for fuel mapping.
2. Maps and links of lands that have fuel maps. Users will point to an area to see if fuel maps exist and then link to the source of these fuel maps.
3. A list of references and contacts for mapping fuels.

The web site serves as the output product for this task (Product 4).

2.0 Research Phase

Active research into the mapping of fuels at multiple scales using remote sensing and biophysical modeling is critical because current technology is often inadequate, inappropriate, inaccurate, and expensive for fuels mapping (Keane et al. 1998b, Keane et al. 2001). We explored and developed new methods and remotely sensed products to accurately, comprehensively, and consistently map those ecosystem attributes, including fuels, useful to fire and fuels management, and then develop the standard methodologies or protocols for using these tools to map fuels for other land areas. We especially concentrated on the EOS imagery on the Terra platform as important imagery sources that will play a crucial role in the future of fuels mapping. We grouped these tasks into three areas:

2.1. Operational fuel mapping. Investigated methods to use currently available and widely used remote sensing products and ecological models to map fuels.

2.2. Terra EOS imagery research. Investigated the potential to use various imagery products from sensors on the Terra platform for fuel mapping.

2.3. New remote sensing applications. Investigated the potential for other airborne imagery, primarily Lidar, to map fuels.

The linkage of the tasks is presented below structured by task group.

2.1 Operational Fuel Mapping

Task 2.1.1- New Fuel Characterization Schemes (see PIs below)-- The first important project was to develop a new national fuels characterization schemes that can be used for all land management applications, especially fire behavior and fire effects prediction. This new scheme will improve the detail in current fuel models so that they can be implemented at multiple scales. This task was funded by the USDA Forest Service Fire and Aviation Management and the Joint Fire Sciences Program. Scientists from the Fire Science Laboratory and Pacific Northwest Research Station developed comprehensive fire behavior and fire effects fuel classification systems using field data, simulation modeling, and photo series information. This task is **not** explicitly included as part of this NASA project, but it is critical because it provides the linkage from fuel classes to fuel map categories, which then provides the vehicle to map fuels for many applications use the most state-of-the-art fuel models. All of these new classifications will be mapped for the entire US in the LANDFIRE project (presented next). There are three products generated from this task:

1. A new set of fire behavior fuel models (Scott, Burgan, Andrews, Finney) (Product 5). The old set had only 13 fuel models to describe all fuel conditions in the US at any scale. This new set has 44 fuel models that should cover all situations of fuel characteristics for the US (see Product 5).

2. A set of fuel characterization classes (FCC) (Sandberg, Ottmar, Alvarado). A system was designed to build fuelbeds for mapping fuels across the landscape. This system contains field data from over 1000 plot-level fuel beds to aid in fuel bed design. Results from this effort is available from the website http://www.fs.fed.us/pnw/fera. This effort was entirely funded by the Joint Fire Sciences Program, but is included here because it allows the mapping of fine scale fuel models for small landscapes (see Product 6).

3. A fuel classification system (Keane). As part of the LANDFIRE project (presented next), we developed a natural fuels classification system that classifies fuelbeds into various groups based on the loading of 12 fuel components such as duff, litter, twigs, and branches. This effort is currently in a research phase and products are not available yet. All products from this effort will be posted on the LANDFIRE web site (www.landfire.gov).

Task 2.1.2- Integrating Gradient Modeling with Remote Sensing for Fuels Mapping (Keane, Rollins)-- As mentioned, spectral imagery alone is not a sufficient tool for mapping fuel classes because of canopy obstruction. Spectral clusters, such as those produced from EDC TM and EOS products, need ancillary data describing the biophysical environment to accurately discriminate between fuel classes. Many ancillary spatial data layers can be used to quantify biophysical attributes such as the STATSGO soils maps, digital elevation models (DEM), and annual precipitation maps, but these variables do not directly describe the environmental processes governing fuel dynamics such as climate, ecosystem productivity, decomposition, and litterfall. What is needed is a method to generate layers that represent the important biophysical,

ecophysiological, and vegetational processes that dictate fuel characteristics. These maps can then be used in conjunction with spectral imagery to map fuels.

We have been developing a biophysically-based gradient model to spatially map ecosystem characteristics for the past three years (Keane et al. 1996). This model synthesizes field data into environmental gradients that can be used to predict those entities important to land management such as cover type, productivity, fire regime, and in this case, fuels. We do this by linking field data to an extensive set of ecosystem process models that simulate and compute important ecosystem attributes, such as net primary productivity, transpiration, decomposition, and respiration, across multiple temporal and spatial scales. These simulated attributes are then added to the biophysical gradient model for use in mapping ecosystem characteristics.

This gradient model approach has many advantages. First, since field data are taken along biophysical gradients, the model can be used at any scale, from site to project to watershed to region, as long the same gradients are represented within that spatial scale. Second, data collected for this model never become obsolete because they quantify environmental gradients, and do not represent static conditions on a piece of ground. Lastly, other important fuel and vegetation characteristics can be mapped using the gradient approach. Many ecosystem characteristics such as tree densities, hiding cover, and leaf area, were measured along with fuels at each field plot, so these data are available to be used as dependent variables in the gradient model to predict their occurrence across the landscape. Such ancillary data may prove to be critically important for prioritizing fuel treatments and evaluating effects of fuel treatments.

The final product was a Landscape Ecosystem Inventory System where integrated ecosystem plot-level sampling were integrated with remotely sensed data and extensive spatially mapped ecosystem gradients to map vegetation and fuels characteristics (see Product 7). Extensive field data collected on the Kootenai and Nez Perce National Forests in Montana and Idaho (Keane et al. 1996) were used to test and refine the biophysical gradient model for this project. We will generate biophysical data layers for these Forests using a series of climate, weather, and biogeochemical simulation models, and then we linked them with LANDSAT 7 TM imagery to map fuel models. This system was then refined and integrated in the LANDFIRE project. This system was published in a Government Technical Report (Product 7) and a paper submitted and accepted to Ecological Applications (see Publications list).

Task 2.1.3- EDC TM Spatial Data Base (Zhu and Ohlen) -- It is important to develop a basic imagery fuel data set from which any fire management agency in any part of the country can accurately and consistently prepare fuels characterization maps for fire management mapping and modeling activities such as FARSITE. And since millions of dollars are spent each year on wildfire management, it is imperative that these base fuels layers be developed **now**, as quickly and expediently as possible. These maps need to be consistent on a nationwide scale so there must be some conformity in the basic data used to produce the maps. In the near term we look to Landsat Thematic Mapper (TM) data to provide the spectral information needed to map vegetation and fuel characteristics. A combination of TM data with ancillary data layers that describe soils, topography, potential vegetation, climate, and other biophysical themes can provide a the means for a national map of fuels characterization. However, TM data is limited in its ability to discriminate fuels (Keane et al. 1998a). Therefore, in the future we look to EOS sensors to improve the base imagery data set and increase fuel mapping accuracies.

In the past, a major barrier to using Landsat TM data for large-scale projects was the cost of acquiring, processing, and merging the data. Moreover, land management agencies rarely have the expertise, computer facilities, or time to perform the initial processing of TM data including

geo-rectifications, image corrections, and spectral classifications. Fortunately, the EROS Data Center (EDC) in cooperation with a consortium of federal agencies, including the Forest Service has initiated the Multi-Resolution Land Characteristics (MRLC) project. The MRLC project has produced a wall-to-wall nationwide data set of leaf-on and leaf-off 1991-1993 vintage Landsat TM data. The TM data are georegistered and corrected for terrain effects. The MRLC consortium will develop a second generation wall-to-wall data set using Landsat 7 data acquired in 2001-2002. As part of the MRLC activities, EDC is currently creating a 26 class land cover data set at 30 meter resolution for the conterminous US (www.epa.gov/mrlcpage/index.html). This data set is being developed using the Landsat TM data set in conjunction with ancillary data layers that describe soils, topography, and potential vegetation. Presently, the land cover data set is finished for most states on the eastern seaboard and the entire conterminous US is to be completed by the year 2000. Work in western US will be expedited as part of this proposal. Purchasing and processing of data for Alaska will also be expedited. EDC has classified nearly all these scenes to spectral cluster classes for use in fuels mapping.

It was immediately apparent that the 26 land cover class information data set alone would not be adequate for mapping fuel characteristics at fine resolutions. However, the intermediate products from the land cover mapping process can provide in the information needed for mapping fuel characterization classes. In the land cover mapping process, a primary component is the vegetation characterization as depicted by the TM data. To capture these characteristics, spectral cluster classes from an unsupervised classification of the TM data are generated from large multi-scene TM mosaics. Generally 90 cluster classes were extracted from each mosaic. For land cover mapping, each cluster class is assigned to one or more land cover classes based on aerial photo interpretation. However, in most cases, individual cluster classes represent several land cover classes so these cluster classes were refined to 26 classes by constructing models that use the appropriate ancillary spatial information.

For mapping fuels, it was originally envisioned that EDC would provide the cluster class information in conjunction with other ancillary data in a land characteristics data base for the contiguous US. This **EDC spatial data base** would have included the EDC cluster maps, tabular summaries of ancillary data characteristics for each cluster class, and the ancillary data layers. These summaries and the individual ancillary data layers could have been used by field staff at the various land management agencies to derive the fuels characterization maps.

However, the fire seasons of 2000 and 2001 caused many fire management agencies to request a comprehensive, fine scale fuel map for the entire US that was much more detailed than the proposed EDC spatial database. So, in 2002, USDA Forest Service Fire and Aviation Management and USDI USGS funded an effort to map fuels across the US using LANDSAT 7 imagery. This project, called LANDFIRE, effectively rendered the proposed EDC spatial database obsolete, so we decided to put the funding for this project into research needed to implement the LANDFIRE project.

LANDFIRE is a **national multiscale fire, ecosystem, and fuel assessment mapping and modeling project** that will generate, for the first time, comprehensive, wall-to-wall, high resolution (30-meter pixels) map coverages of fire, fuel, and ecosystem condition across the conterminous United States for fire and land management planning (see www.landfire.gov which is Product 8). This project will provide the consistent and comprehensive spatial data needed for implementation of the National Fire Plan Cohesive Strategy. This process will be repeated every 10-years (depending on technology and resources) to detect landscape change for assessment of the success of the Cohesive Strategy implementation. Initial development of maps, tools, and change detection for the 650 million acres of wildlands in the western U.S. will take 5 years at a

cost of about 35 million dollars, or about $0.01 per acre. Currently, all tools, methods, and protocols needed to map fuels and create LANDFIRE products are being prototypes on two areas in western Utah and western Montana.

The LANDFIRE project was born from a similar effort that produced a 1-km fuel condition map for coarse scale implementation of the Cohesive Strategy. Subsequent discussions between the Forest Service Washington Office, Congressional and Administration staffs, and Government Accounting Office (GAO) solidified support for LANDFIRE to provide a nation-wide fine scale map product to assess fire and fuel condition classes in a consistent manner for mid-scale planning. The LANDFIRE project brings together scientists, computer specialists, geographers, and ecologists from many agencies and institutions including USDA-FS Rocky Mountain Research Station, USDA-FS Pacific Northwest Research Station, USDA-FIA, USGS EROS Data Center, Universities of Montana and Idaho, and several private companies. It is funded by USDA Forest Service Fire and Aviation Management and is jointly managed by the USGS EROS Data Center (Zhu) and the Fire Sciences Laboratory, Rocky Mountain Research Station (Keane).

LANDFIRE will assess three important fire characteristics on the landscape: fire potential, fuel condition, and ecosystem status. Fire potential will be assess by computing potential fire behavior, effects, and danger characteristics across an analysis landscape for a representative time period (1980-1998). These characteristics are computed from a fuels map and a spatial weather database. The fuels map is created from a national cover type and structural stage map that is being developed by USGS at EROS Data Center. The weather database is being developed at University of Montana. Fuel condition and ecosystem status are computed as a comparison of existing conditions to historical conditions. Existing conditions are taken from the EROS vegetation maps and the generated fuels map. Historical conditions are taken from ecosystem simulations of multiple scale landscapes using model parameters computed from historical fire data. The LANDSUM model will be used to simulate historical range and variation of cover type, structural stage, and fuel loading conditions for the time period 1000 to 2000 AD. LANDSUM uses successional pathways and fire return intervals that will be created inside the VDDT program using field data and available literature. The most critical component in LANDFIRE mapping and modeling tasks is an extensive georeferenced field database for 1) integrating field data into satellite mapping models, 2) accuracy assessments, 3) simulation model parameterization and validation, 4) biophysical mapping, and 5) quantification of ecosystem components (e.g., crown fuels). LANDSUM stratifies succession models by biophysical settings, which will be mapped across the US using environmental gradients simulated by biogeochemical models. Biophysical settings are also important for stratifying cover type and structural stage classifications for fuel map creation.

LANDFIRE will produce a process for determining fire potential, fuel condition, and ecosystem status for all lands in the conterminous United States. This process will contain a wide variety of national GIS layers, GIS programs, computer simulation models, and computer analysis programs for determining the spatial extent of the fire characteristics mentioned above. Each of the tools in the process can be used in a LANDFIRE context or on their own. Major intermediate LANDFIRE products include a national 18-year daily weather database, a vegetation map, a percent cover map, and a structural stage map for the US. A landscape simulation model called LANDSUM will be parameterized to execute for any area. A fire potential program called LANDFIRE will compute fire behavior, effects, and danger maps for any day or place in the US. A biogeochemical model called LF-BGC will be built to simulate ecosystem dynamics for any landscape in the US. The EROS Data Center will provide a number of intermediate spatial products because of LANDFIRE's association with the MRLC (Multi-

Resolution Land Cover) project. These products include national elevation, slope, aspect and soil ancillary data layers, and Landsat 7 imagery derivatives for three time periods.

There is an intimate linkage of the LANDFIRE project to this NASA project. First, all research generated from this NASA project is directly useful to the LANDFIRE project. Second, all spatial and field data collected for the NASA project will be used in the LANDFIRE project. And last, LANDFIRE could not be possible if it weren't for the critical research generated by this NASA project (as describe in the next set of tasks). Output products for LANDFIRE are posted on its website (see Product 7).

Task 2.1.4- TM-derived NDVI for mapping fuels (Van Wagtendonk). A task that was not proposed but was included in this study because funding from this study paid for the collection of some field data describing fuel conditions used in the task. This task involved mapping fuels using existing TM data using NDVI (see Product 9). This project was extremely successful but require abundant LANDSAT TM imagery over many times.

2.2 EOS Terra imagery research

Most spectral imagery such as TM, MSS, and SPOT do not discriminate vegetation and fuels to the accuracy needed for fire management (Keane et al. 1998a). Therefore, the imagery generated from sensors on EOS satellites will play a critical role in the future of fuels mapping and fire management. We have targeted the spectral sensors ASTER and MISR as critical to this project's success. The long term plan is to continually update the national LANDFIRE spatial data base using EOS imagery products. Then, anyone can download a section of this database for their area of concern to assign fuel characterization classes to classification categories using the methodologies generated from the above effort.

The high resolution and large swath width of the ETM+ sensor will allow the replication of the LANDFIRE TM map effort mentioned above using the same field data sets mentioned later in this proposal. The ASTER imagery will provide better spectral resolution but at smaller footprints. These layers could replace ETM+ layers in the future, especially in ecosystems where ASTER band widths discriminate fuel characteristics better than ETM+. These fine scale, high resolution imagery products would require a great deal of effort to synthesize a national data set such as the EDC TM cluster map. Therefore, this effort may need updating every 10 to 20 years. However, large fires and active land management may outdate these layers for some fuels applications such as a national hazard assessment. Lastly, it is doubtful that any of these spectral sensors can be classified to the high accuracies needed for fine-scale fire management decision support in sensitive areas such as the urban interface. Fundamental limitations of the spectral resolution and vegetation character do not allow accurate discrimination of vegetation structure to the detail needed for accurate, fine-scale fire simulations. Therefore, we propose Lidar as the sensor to remotely sense vegetation and fuels structure and composition in areas where loss of human life and property may be very important.

We tested the applicability of some EOS sensors to accurately and consistently detect fuel characteristics for fire management on several field sites established around the US. We obtained this imagery for various field sites and then created a classified fuel map of the area with generic categories. We selected MISR and ASTER imagery to evaluate for fuel mapping. We concluded that a MODIS comparison probably would not be relevant to this project because the large spatial resolution and frequent temporal resolution wouldn't be appropriate for mapping

fuels for fire management. Here are a list of the tasks that were funded in this subject area for this NASA project.

Task 2.2.1- Fuel Mapping using MISR imagery (Schmidt, Keane). This task used MISR imagery to map canopy cover across western Montana and northern Idaho (see Product 10). Canopy cover is used to simulate crown fire initiation and spread, and it is directly related to another canopy fuel characteristic, bulk density, which is a major input parameter in nearly all crown fire models. Results showed MISR seem to contain more information for more accurately discriminating canopy cover but the imagery is difficult to analyze and has a spotty temporal and spatial coverage, which might limit its usefulness for fuel mapping.

Task 2.2.2- Fuel Mapping using ASTER imagery and a fusion of other spatial data products (Gessler, Morgan, Hudak). The study "Evaluating ASTER satellite imagery for mapping and characterizing fuels for forest fires in mixed conifer forests of northern Idaho" was initiated in spring 2003 with the University of Idaho and USDA Forest Service (see Product 11). This project will use ASTER imagery to map the 13 fire behavior fuel models for two small landscapes in Idaho. These maps will be formatted to be input to the FARSITE computer simulation model. This study is currently being conducted and results aren't expected until summer 2005. The investigators are also going to fuse Lidar with ASTER and IIKONOS to improve fuel mapping for the same areas.

2.3 New Remote Sensing Applications

Task 2.3.1- Lidar Fuel Mapping -- The inability of current optical sensors, including the TM sensor mentioned above, to "see" below the forest canopy is a major shortcoming for mapping fuels. This usually results in low map accuracies and inconsistent class assignments (Keane et al. 1998a), but these sensors are the best available now and in the near future. However, there are new remote sensing technologies from satellite and airborne platforms that have applications in mapping fuel characteristics, and Lidar seems to show the greatest promise.

Lidar is an active remote sensing technique that can provide relatively precise measurements of canopy top height, vertical canopy distribution, surface roughness, and ground surface elevation (Nelson et al. 1988, Ritchie et al. 1992, Weltz et al. 1994, Naesset 1997, Nelson 1997, Nelson et al. 1998). Lidar uses light emissions to measure ranges between itself and a reflective surface. Airborne or space borne Lidar instruments emit pulses of electro-magnetic radiation toward the earth and collect the back scatter using nanosecond-resolution clocks to the round-trip propagation of each pulse (Bufton 1989). The speed of light is then used to calculate the distance from sensor to target. The intensity and temporal distribution of returned pulses (back scatter radiation) are used to determine earth surface parameters such as vegetation height and slope. The interaction of the light pulse with the earth surface (leaves, rocks, twigs, soil) alters its timing and intensity which creates a unique signal for mapping terrestrial characteristics like soils. The primary goal of earth surface Lidar remote sensing is to quantitatively link this distorted return signal to surface structural variables.

Although lidars have been used for almost three decades in the space and atmospheric sciences to map topographic and atmospheric characteristics of planets (including earth), it is only recently that research has turned toward the earth's surface with the goal of accurately measuring vegetation structure. To date, most Lidar studies of the earth have utilized airborne or ground-based sensors over relatively small land areas at inordinately high prices relative to land management. However, Earth Systems Science Pathfinder's (ESSP) Vegetation Canopy Lidar

(VCL), a multi-laser space borne system to be launched in February of 2000, promises to provide systematic, high-spatial resolution global coverage for the first time (Dubayah et. al. 1997). The launch of VCL will be the first opportunity for land management agencies to acquire high-quality vegetation structure information remotely for large land areas. It is believed that this sensor will allow detailed characterization of vertical and horizontal forest fuel distributions at high spatial resolution. Furthermore, Lidar-derived fuels data will serve as inputs into spatially explicit fire behavior models like Finney's (1998) FARSITE. Lidar will improve the accuracies of fuels maps but at a significant cost. Its use in fuel mapping might be initially confined to the highly sensitive urban-interface because high fuel mapping accuracies are essential for defensible and scientifically-base fire management.

We used Lidar to map fuels for the Tenderfoot Experimental Forest, Lewis and Clark National Forest (65 km^2) and investigated the following relationships:

1. *Define the relationships between Lidar return data and forest/fuel structure.*
2. *Develop a methodology to accurately characterize canopy, transition (ladder), and surface fuels using multi-return Lidar data.*
3. *Determine the ability of Lidar to measure biomass density for smoke emissions models.*
4. *Validate the belief that Lidar will provide significantly better discriminatory power for fuels mapping than existing remote sensing techniques.*
5. *Evaluate the potential cost-effectiveness of Lidar for large-scale fuels mapping.*

This task found fuel maps of fire behavior fuel models created from Lidar were very accurate (>80%) and had the imagery had the potential for remotely sensing other fuel characteristics such as crown bulk density, canopy cover and stand height. However, the high cost of obtaining and processing Lidar data might deter the operational use of Lidar in mapping fuels across large areas. Products from this tasks are a final report (see Product 12). Results from this task will be published in various journals (see Publication List).

2.4 Study Area Data Compilation

In the original proposal, we proposed to develop a series of databases for five study areas on which to test our methods and conduct our research. We identified six sites where the protocols and maps generated from above tasks will be independently tested. Each site is composed of a mosaic of land ownership that includes private, state, and federal (USDA Forest Service, USDI National Park Service, Bureau of Land Management, Bureau of Indian Affairs). These sites run the gamut of data availability, size, topography, and ecosystems.

Yosemite National Park (California) -- This area has extensive spatial data layers and an intensive network of over 8,000 field plots. In addition to the single-scene satellite image map developed by van Wagtendonk (1998) for the entire Park, new maps using a temporal sequence of TM scenes are in preparation by van Wagtendonk et al (1998).

Nez Perce National Forest (Idaho) -- This area was selected because it was extensively sampled for the Keane et al. (1996) gradient modeling project and it has a comprehensive GIS of the entire complex and an extensive ground-truth collection. No fuels layers yet exist for this area.

Tenderfoot Experimental Forest (Montana) -- This 3,000 ha area was intensively sampled for fuels and vegetation on a 300 meter grid so the spatial and temporal distribution of

ground truth is extensive. This area will also be treated as part of an ecosystem management project which will allow these methods to be tested across two time periods to quantify change in fuel dynamics which provides a test of the sensitivity of fuels mapping methodologies.

Gila National Forest Complex (New Mexico) -- Fuels for this 1.2 million ha area are currently being mapped using Landsat TM imagery and potential vegetation types by Bob Keane and staff at the Intermountain Fire Sciences Laboratory. This provides an excellent comparison with the EDC cluster map because Keane used the same TM data but generated spectral clusters with different parameters and techniques. Over 2,000 plots comprise an extensive ground truth layer.

Frostfire (Alaska) -- This small land area will be extensively sampled for fuels and vegetation during the summer of 1998. An EDC cluster map will be linked to the GIS and ground truth data for this site to validate and refine fuel mapping methodologies. Dave Sandberg, Roger Ottmar, and Ernesto Alvarado will perform this validation task.

Southern Utah (Utah) -- Fuels maps for the entire southern half of Utah will be developed from the methods described here. This study will be linked to another proposed study "Southern Utah Fuels Management Demonstration Project" where they will build the fuels maps using techniques presented here and we will validate the maps. This area was selected because there are few ground-truth sources, spatial data layers, and fuel maps available so the fuels mapping project would essentially start from the beginning. Secondly, this area is managed by a melange of government agencies including USFS, BLM, NPS, and state.

Extensive spatial data were collected for these areas but it was soon evident that imagery for these study areas was nearly impossible to obtain in a timely fashion. Therefore, we allowed investigators to select study areas where all imagery and corresponding core spatial data layers were available thereby rendering the five study areas irrelevant. The GIS layers for these areas are available from various scientists on this project and can be compiled upon request. However, they were not compiled for this report because not all studies used these areas for development.

3.0 Implementation Phase

Task 3.1-Standardized Protocols (Keane). The third part of this project was to distribute a standardized set of protocols for fuels mapping to fire management in the form of computer programs, publications, and training sessions. These methods were to be designed so fire management personnel can match the characteristics of their project area with the correct or most appropriate fuels mapping methods. However, our research in this project found that it would be very difficult to develop a standard set of protocols for the following reasons:

1. Core data layers don't exist for many parts of the US.
2. Expertise at various agencies is extremely variable and it was difficult to devise a protocol around all levels of experience.
3. Field data were not well distributed across geographical regions, ecosystem types, fuel types, and topography.
4. The image processing and analysis software and hardware available at the various agencies varied greatly.

Therefore, we decided to integrate this task into LANDFIRE and let it produce the primary fuel layer. Also, LANDFIRE will produce a series of documents that will detail how fuel maps were created so that managers can replicate the process.

Task 3.2- Fire risk and hazard evaluation (Keane, Rollins). Perhaps the most critical need in fuels treatment planning and implementation is the development of a tool that creates **fire hazard and risk maps** that identify those areas where wildland fire can cause significant damage based on fire behavior, topography, human habitation, and transportation structures. This can serve as a vehicle to prioritize and schedule fuels treatments in space and time. It would be especially useful if this tool was integrated with other existing data sources so that both spatial and temporal analyses of fire hazard and risk possible.

We have built and are currently testing a software program called FIREHARM (a FIRE HAzard Rating Model) that computes probability maps of fire hazard across any spatial domain for the LANDFIRE project. FIREHARM accesses the DAYMET weather database (18 years of daily weather including temperate, precipitation, and radiation at 1 km resolution for US) and a list of polygons to compute five measures of fire behavior, five measures of fire danger, and five measures of fire effects for every day of the year. The user would then specify a threshold value and FIREHARM would compute the probability of that event across the 18 years of weather for every pixel on the landscape. These probabilities can then be multiplied or added to compute the probability of a combined event. In addition, FIREHARM will take a list of fuel moisture values for each of the landscape polygons to compute estimates of the five fire behavior, danger, and effects for that weather situation. These values can then be mapped back on the landscape to product fire hazard indexes or fire severity indexes to plan prescribed burning treatments and wildfire rehabilitation activities.

FIREHARM is now being tested for applicability for all areas of the US. This model will be released in spring of 2005. A manual and user's guide is currently being written (see Publications list).

Product List

Product 1. Paper summarizing current fuel mapping approaches and strategies.

Keane, R. E., R. E. Burgan, and J. V. Wagtendonk. 2001. Mapping wildland fuels for fire management across multiple scales: Integrating remote sensing, GIS, and biophysical modeling. International Journal of Wildland Fire **10**:301-319

Product 2. Special issue of International Journal of Wildland Fire "Integrating spatial technologies and ecological principles for a new age in fire management. Issue 10

Product 3. A CD with a collection of over 100 submitted papers titled "Proceedings from the Joint Fire Science Conference and Workshop: Crossing the millennium: Integrating spatial technologies and ecological principles for a new age in fire management".

Product 4. The fuels mapping coordination web site: www.frames.gov

Product 5. The new set of fire behavior fuel models.

Product 6. The new set of fuel characterization classes. See web site: http://www.fs.fed.us/pnw/fera/

Product 7. The published report:

Keane, R. E., C. McNicoll, M. G. Rollins, and R. A. Parsons. 2002. Integrating ecosystem sampling, gradient modeling, remote sensing, and ecosystem simulation to create spatially explicit landscape inventories. General Technical Report RMRS-GTR-92, USDA Forest Service, Rocky Mountain Research Station, Fort Collins, CO

Product 8. The LANDFIRE web site www.landfire.gov

Product 9. The manuscript:

Van Wagtendonk, Jan W. and Ralph R. Root. 2003. The use of multi-temporal Landsat Normalized Difference Vegetation Index (NDVI) for mapping fuel models in Yosemite National Park, USA. In press to Remote Sensing of the Environment

Product 10. Kirsten Schmidt masters thesis.

Product 11. Proposal for ASTER fuel mapping study with University of Idaho

Product 12. The Lidar Report:

Seielstad, C.A. 2003. Estimating surface fuels attributes and FBPS fuel models with airborne laser altimetry. Final Report for RJVA 00-JV-1122220-48-018 on file at Fire Sciences Laboratory, Missoula, MT.

Publication List

Publications, Posters, Presentations, and Web Sites
NASA Funded Project AFRR-0000-0175

PUBLICATIONS

Published

Keane, R.E., Burgan, R.E., and J. Van Wagtendonk. 2001. Mapping wildland fuels for fire management across multiple scales: Integrating remote sensing, GIS, and biophysical modeling. **International Journal of Wildland Fire** 10(3-4):301-319.

Alvarado, Ernesto; Sandberg, David V.; Ottmar, Roger D. 2000. Mapping wildfire severity in boreal forest based on aerial photography and remote sensing [Abstract]. Fire Conference 2000: The first national congress on fire ecology, prevention and management; 2000 November 27-December 1; San Diego, CA. Davis, CA: University of California, University Extension.

Sandberg, David V.; Ottmar, Roger D. 2000. FROSTFIRE: GIS applications and remote sensing [Abstract]. Fire Conference 2000: The first national congress on fire ecology, prevention and management; 2000 November 27-December 1; San Diego, CA. Davis, CA: University of California, University Extension.

Keane, R.E., R.E. Parsons and P. Hessburg. 2001. Estimating historical range and variation of landscape patch dynamics: Limitations of the simulation approach. **Ecological Modelling 151(1):29-49**

Seielstad, C.A. 2003. Estimating surface fuels attributes and FBPS fuel models with airborne laser altimetry. Final Report for RJVA 00-JV-1122220-48-018 on file at Fire Sciences Laboratory, Missoula, MT.

Keane, R. E., C. McNicoll, M. G. Rollins, and R. A. Parsons. 2002. Integrating ecosystem sampling, gradient modeling, remote sensing, and ecosystem simulation to create spatially explicit landscape inventories. General Technical Report RMRS-GTR-92, USDA Forest Service, Rocky Mountain Research Station, Fort Collins, CO

Schmidt, Kirsten M. 2003. Using multi-angle imaging spectroradiometer (MISR) data to distinguish tree cover. University of Montana, Missoula, MT. Master's Thesis. 68 pages.

In Press

Van Wagtendonk, Jan W. and Ralph R. Root. 2003. The use of multi-temporal Landsat Normalized Difference Vegetation Index (NDVI) for mapping fuel models in Yosemite National Park, USA. In press to **Remote Sensing of the Environment**.

Rollins, M., R.E. Keane, and R. Parsons. 2002. Mapping fuels and fire regime using gradient analysis, ecosystem modeling, and remote sensing. **Ecological Applications.** [In Press].

Van Wagtendonk, J. and R. Root. 2002. The use of multi-temporal Landsat Normalized Difference Vegetation Index (NDVI) data for mapping fuel models in Yosemite National Park, USA. **Remote Sensing of the Environment** [In Press].

Seielstad, C.A. and L.P. Queen. 2003[in review]. Using airborne laser altimetry to determine fuel models for estimating fire behavior. **Journal of Forestry** [in press].

In Preparation

Keane, Robert E. 2005. Describing biophysical environment for gradient modeling and ecosystem mapping using WXFIRE. USDA Forest Service Rocky Mountain Research Station General Report RMRS-GTR-XX.

Keane, Robert E. 2005. Simulating historical landscape dynamics using the landscape fire succession model LANDSUMv4. USDA Forest Service Rocky Mountain Research Station General Report RMRS-GTR-XX.

Keane, Robert E. 2005. Mapping fire hazard with the FIREHARM model. USDA Forest Service Rocky Mountain Research Station General Report RMRS-GTR-XX.

POSTERS

Rollins, M., R.E. Keane, and R. Parsons. 2002. Mapping fuels and fire regime using gradient analysis, ecosystem modeling, and remote sensing. **Emulating Natural Disturbances Conference. Sault Ste. Marie, Ontario, Canada.**

PRESENTATIONS

Rollins, M. and R.E. Keane. 2001. Remote sensing and gradient modeling for ecosystem management. IALE 2001 Conference, Phoenix AZ.

There will be a set of presentations on LANDFIRE at the:

5th Symposium on Fire and Forest Meteorology
Joint With
2nd International Wildland Fire Ecology and Fire Management Congress

Here are a list of the talks.

8:00 AM J10D.1 LANDFIRE—A USDA FOREST SERVICE AND DEPARTMENT OF INTERIOR PARTNERSHIP FOR NATIONAL FIRE/FUELS ASSESSMENT. Matthew Rollins, US Forest Service, Missoula, MT

8:30 AM J10D.2 DEVELOPING THE SPATIAL PROGRAMS AND MODELS FOR IMPLEMENTATION OF THE LANDFIRE PROJECT. Robert E. Keane, USDA Forest Service, Rocky Mountain Research Station, Missoula, MT; and M. Rollins and R. Parsons

9:00 AM J10D.3 BIOPHYSICAL SETTINGS -- LINKING LANDSCAPE PATTERNS TO ECOPHYSIOLOGICAL PROCESSES. Lisa Holsinger, USDA, Missoula, MT; and R. Parsons, M. Rollins, E. Karau, and A. Keyser

9:30 AM J10D.4 MAPPING NATIONAL VEGETATION TYPES AND STRUCTURE: A REPEATABLE AND CONSISTENT STRATEGY. Zhiliang Zhu, USGS, Sioux Falls, SD

10:00 AM COFFEE BREAK

10:30 AM J10D.5 RESULTS OF THE VEGETATION MAPPING COMPONENT OF THE LANDFIRE PROTOTYPE STUDY. Chengquan Huang, USGS/EROS Data Center and SAIC, Sioux Falls, SD

11:00 AM J10D.6 PREDICTIVE MAPPING OF FIRE REGIMES. Russell A. Parsons, USDA Forest Service, Fire Sciences Lab, Missoula, MT; and R. E. Keane and M. G. Rollins

11:30 AM J10D.7 POTENTIAL MANAGEMENT APPLICATIONS OF THE LANDFIRE PRODUCTS. Donald Long, USDA Forest Service, Missoula, MT; and M. Rollins and W. Hann

WEB SITES

www.landfire.gov -- The web site for the LANDFIRE project.
www.firelab.org -- The Fire Lab Web site hosting results from NASA projects
www.firelab.org/firemon -- A web site for fuel sampling and monitoring
www.frames.gov -- A web site that will contain core field data and spatial data layers for fuel mapping